

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



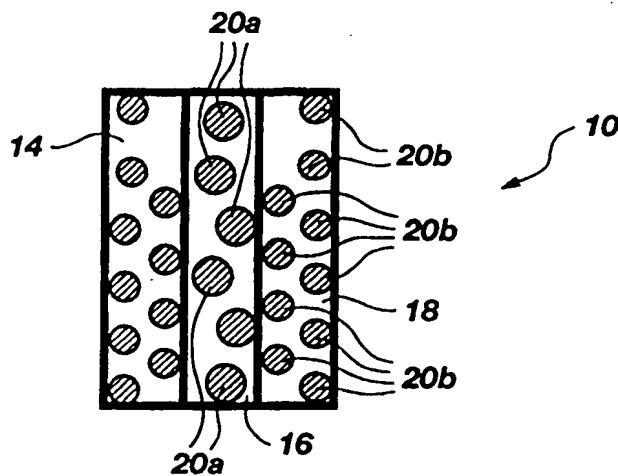
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> :	A1	(11) International Publication Number: WO 98/45092 (43) International Publication Date: 15 October 1998 (15.10.98)
B24D 11/00		
(21) International Application Number:	PCT/US98/05951	(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).
(22) International Filing Date:	26 March 1998 (26.03.98)	
(30) Priority Data:	08/832,852 4 April 1997 (04.04.97) US	
(71)(72) Applicant and Inventor:	SUNG, Chien-Min [US/-]; 4 Lane 32, Chung-Cheng Road, Tansui, Taipei County 251 (TW).	
(74) Agents:	BATEMAN, Randall, B. et al.; Thorpe, North & Western, L.L.P., P.O. Box 1219, Sandy, UT 84091-1219 (US).	Published <i>With international search report.</i>

(54) Title: ABRASIVE TOOLS WITH PATTERNED GRIT DISTRIBUTION AND METHOD OF MANUFACTURE

(57) Abstract

An abrasive tool (10) that contains abrasive particles (20) distributed in a predetermined pattern. Such a pattern is produced by fabricating two-dimensional slices (14, 16, 18) and assembling them. Abrasive particles (20) may be incorporated during the process of making these slices, or they may be planted afterwards into these slices which contain matrix powder. The planting may be guided by a template with apertures laid in a specific pattern.



**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

**ABRASIVE TOOLS WITH PATTERNED GRIT DISTRIBUTION  
AND METHOD OF MANUFACTURE**

5

**BACKGROUND OF THE INVENTION**

1. Field of the Invention

The present invention relates to improved  
10 abrasive tools used for cutting, grinding and the  
like. More particularly, the present invention  
relates to improved abrasive tools wherein abrasive  
particles are distributed in a predetermined pattern  
in a matrix powder in order to decrease cost and/or  
15 increase the useful life of the tool.

2. State of the Art

Abrasive tools have long been used in numerous  
applications, including cutting, drilling, sawing,  
20 grinding, lapping and polishing materials. Because  
diamond is the hardest abrasive material and cubic  
boron nitride is the second hardest, the two materials  
have been widely used as superabrasives on saws,  
drills, and other tools which utilize the abrasive to  
25 cut, form or polish other hard materials. It is  
estimated that the total value of superabrasive tools  
now consumed world wide is over is over 5 billion U.S.  
dollars per year. More than half of the superabrasive  
tools are believed to be consumed in sawing and

drilling application such as cutting stones, concretes, asphalts, etc.

Superabrasive tools are particularly indispensable for applications where other tools lack  
5 the strength and durability to be practical substitutes. For example, in the stone industry where rocks are cut, drilled, or sawed, diamond tools are the type which are sufficiently hard and durable to make the cutting, etc., economical. If superabrasives  
10 were not used, many such industries would be economically infeasible. Likewise, in the precision grinding industry, superabrasive tools, due to their superior wear resistance, are uniquely capable of developing the tight tolerances required, while  
15 simultaneously withstanding wear sufficiently to be practical.

Despite the tremendous improvements which diamond and cubic boron nitride have provided for cutting, drilling and grinding tools, there are still several  
20 disadvantages which, if overcome, would greatly improve performance of the tools, and/or reduce their cost. For example, the abrasive diamond or cubic boron nitride particles are not distributed uniformly in the matrix that holds them in place. As a result,  
25 the abrasive particles are not positioned to maximize efficiency for cutting, drilling, etc., and for production costs of the tools. In some instances, the abrasive particles are disposed too close together.

In other instances, the abrasive particles are disposed to far apart from one another.

In all applications, the separation between abrasive particles determines the work load each particle will perform. Improper spacing of the abrasive particles typically leads to premature failure of the abrasive surface or structure. Thus, if the abrasive particles are too close to one another, some of the particles are redundant. The particles are present, but provide little or no assistance in the cutting, grinding, etc., application. Of course, excess particles add to the expense of the abrasive, due the high cost of diamond and boron nitride. Moreover, these non-performing particles can block the passage of debris, thereby reducing the cutting efficiency. Thus, having abrasive particles disposed too close to one another adds to the cost, while decreasing the cutting efficiency of the tool.

On the other hand, if abrasive particles are separated too far, the work load (e.g., the impact force exerted by the work piece) for each particle becomes excessive. The sparsely distributed particles may be crushed, or even dislodged from the matrix into which they are disposed. The damaged or missing abrasive particles are unable to fully assist in the work load. Thus, the work load is transferred to the surviving abrasive particles. The failure of each

abrasive particle causes a chain reaction which soon renders the tool ineffective to cut, drill, grind, etc.

A typical superabrasive tool, such as a diamond saw blade, is manufactured by mixing diamond particles (e.g., 40/50 U.S. mesh saw grit) with a suitable matrix (bond) powder (e.g., cobalt powder of 1.5 micrometer in size). The mixture is then compressed in a mold to form the right shape (e.g., a saw segment). The "green" form is then consolidated by sintering at a temperature between 700-1200 °C to form a single body with a plurality of abrasive particles disposed therein. Finally, the consolidated body is attached (e.g., by brazing) to a tool body, such as a round blade of a saw, to form the final product.

Different applications, however, require different combinations of diamond (or cubic boron nitride) and matrix powder. For example, for drilling and sawing applications, a large sized (anywhere from 20 to 60 U.S. mesh) diamond grit is mixed with a metal powder. The metal powder is typically selected from cobalt, nickel, iron, copper, bronze, alloys thereof, and/or mixtures thereof. For grinding applications, a small sized (anywhere from 60 to 400 U.S. mesh) diamond grit (or cubic boron nitride) is mixed with either metal (typically bronze), ceramic/glass (typically a mixture of oxides of sodium, potassium, silicon, and aluminum) or resin (typically phenolic).

Because diamond or cubic boron nitride is much larger than the matrix powder (300 times in the above example for making saw segments), and it is much lighter than the latter (about 1/3 in density for 5 making saw segments), it is very difficult to mix the two to achieve uniformity. Moreover, even when the mixing is thorough, diamond can still segregate from metal in the subsequent treatments such as pouring the mixture into a mold, or when the mixture is subjected 10 to vibrations. This diamond distribution problem is particularly troublesome for metal matrix tools. Metal matrix tools may account for more than 60% of the total value of all diamond tools. Within metal matrix tools, diamond saws (circular saws, straight 15 blades, wire saws, etc.) comprise about 80% of the value. Thus, finding a method for increasing life of the abrasive material, and/or decreasing the amount of abrasive which is needed is highly desirable. Such has been accomplished by the invention set forth 20 herein. The invention is applicable to all superabrasive tools, and is particularly effective for diamond saws, the largest value category of all diamond tools.

Over the decades, there have been numerous 25 attempts to solve the diamond distribution problem. Unfortunately, none of the attempted methods have proven effective and, as of today, the distribution of diamond particles in diamond tools is still random and

irregular, except for some special cases such as drillers or dressers, where large diamond particles are individually set by hand in the surface to provide a single layer.

5 One method used in an attempt to make the diamond distribution uniform is to wrap diamond particles with a thick coating of matrix powder. The concentration of diamond particles in each diamond tool is tailored for a particular application. The concentration  
10 determines the average distance between diamond particles. For example, the concentration of a typical saw segment is 25 (100 means 25% by volume) or 6.25% by volume. Such a concentration makes the average diamond to diamond distance about 2.5 times of  
15 the particle size. Thus, if one coats the diamond to 0.75 times of its diameter and mix the coated particle together, the distribution of diamond would be controlled by the thickness of coating and may become relatively uniform. Additional metal powder may be  
20 added as interstitial filler between these coated particles to increase the packing efficiency so the consolidation of the matrix powder in subsequent sintering would be easier.

Although the above described coating method has  
25 certain merit, in practice, the uniformity of coating is very difficult to achieve. There are many chemical methods to coat diamond grit and its aggregates (polycrystalline diamond). For example, Chen and Sung

(U.S. Patent Nos. 5,024,680 or 5,062,865) described a CVD method for coating diamond grit using a fluidized bed. Sung et al (U.S. Patent Nos. 4,943,488 or 5,116,568) described another CVD method for coating polycrystalline diamond by fluidized bed. However, most of these methods can only produce thin coatings (e.g. a few micrometers) that do not affect the diamond distribution. Moreover, chemical coating methods typically require treatment at high temperatures (e.g. greater than 900 °C) that may cause damage to diamond. It is well known that synthetic diamond grit tends to form microcracks above this temperature. These microcracks are formed by the back-conversion of diamond to graphite at high temperature. The back-conversion is induced by the catalytic action of metal inclusions that diamond incorporated during its synthesis. CVD treatments cannot readily make thick coatings, and those which are formulated are often cost prohibitive. Thus, CVD treatments are not practical methods to make diamond distribution uniform in the tool.

There are, however, less expensive mechanical methods (e.g., by tumbling diamond particles with metal powder) that can build up a thick coating on diamond grit, typically at a low temperature that would not cause the degradation of diamond. However, it is very difficult to achieve a thick coating with uniform thickness using such methods.

For example, in attempts to practice the invention described in U.S. Patent No. 4,770,907 C.M. Sung performed "Metal Coating of Saw Diamond Grit by Fluidized Bed" (see p 267-273 of Fabrication and Characterization of Advanced Materials, edited by S. W. Kim and S. J. Park of The Materials Research Society of Korea 1995). It was found that the thickness of coated diamond particles varied considerably. Moreover, only extremely fine (i.e. less than 5 micrometers) metal powders can be coated on diamond effectively. Furthermore, the reproducibility of this method is poor. Hence, although such coating may improve the diamond distribution in the tool, its effect is limited.

Furthermore, in mechanical coating, metal powder is held loosely by an organic binder (e.g., PVA, PEG). The coating may be easily rubbed off during the subsequent mixing process, and thereby losing its intended benefit. Although heat treatment may increase the mechanical strength of the coating, nonetheless, it is an additional step with cost.

There is yet another limitation associated with the current methods of coating diamond particles. Many times a diamond tool requires different sizes of diamond grit and/or different diamond concentrations to be disposed at different parts of the same diamond tool. For example, saw segments tend to wear faster on the edge or front than the middle. Therefore,

higher concentrations and smaller diamond grit are preferred in these locations to prevent uneven wear, and thus premature failure of the saw segment. These segments with different concentration/size combinations (known as "sandwich" segments) are difficult to fabricate by mixing coated diamond with metal powder to achieve a controlled distribution of the abrasive particles in the segment. Thus, despite the known advantages of having varied diamond grit sizes and concentration levels, such configurations are seldom used because of the lack of a practical method.

In summary, current arts are incapable of efficiently controlling the uniformity of diamond distribution in the tool. Likewise, the current methods are inadequate to provide effective control of size variations and/or concentration variations on different parts of the same tool. Moreover, even when the distribution is made relatively uniform, current arts cannot tailor the pattern of the distribution to overcome or compensate for typical wear patterns for the abrasive material, when used for a particular purpose. By resolving these problems, the performance of a diamond and other superabrasive tools can be effectively optimized.

It is estimated that less than 10% of abrasives are actually consumed at work. Most of remainder is wasted due to the low efficiency of using these tools.

Among the various causes of this low efficiency, the inability to place every abrasive at the desired location is a major factor. This invention is aimed to make a revolutionary improvement to overcome the deficiency by eliminating random distribution of abrasive particles. The result would be an abrasive tool with every abrasive particle positively planted at desired positions to achieve the maximum utility. Hence, the performance of the abrasive tool can be optimized.

By making the distribution of abrasive particles uniform or tailored to the particular applications of the tool, then the work load can be evenly distributed to each particle. As a result, the abrasive tool will cut faster and its working life be extended a considerable amount of time. Moreover, by eliminating the redundancy, less abrasive may be needed, thereby reducing the cost of the tool manufacture.

Additionally, if the distribution can be controlled, abrasive tools utilizing diamond or cubic boron nitride can be configured to provide the most efficient wear profile possible.

The present invention resolves these problems and provides the advantages set forth above by providing a method for forming such tools wherein the abrasive particle distribution can be controlled to provide either uniform grit placement, or to provide grit placement which is tailored to the particular wear

characteristics of the tool. Because the distribution of the diamond particles is controlled, the particles can be disposed in patterns which provide for relatively even wear of the abrasive surface, rather than having portions of the surface wear prematurely.

5 As each particle is more fully utilized, there is no need for redundant particles as a back up. Therefore, the cost of making the abrasive tools can be reduced by decreasing the overall amount of superabrasive which is used. For example, the cost of

10 superabrasives (diamond or cubic boron nitride) is so high that it often accounts for about half of the total manufacturing cost of the tool. By maintaining the performance of a superabrasive tool with a

15 substantially lower concentration used in a controlled distribution, significant cost saving may be realized due to the decreased use of the expensive abrasive.

#### SUMMARY OF THE INVENTION

20 It is an object of the present invention to provide a method for forming superabrasive tools, wherein the distribution of the superabrasive grit is controlled to provide improved cutting, grinding, etc., characteristics without requiring an increase in the amount of superabrasive grit used to form the

25 tool.

It is another object of the invention to provide such a method wherein the distribution of the

superabrasive grit is controlled to promote more even wear of the abrasive surface, and thereby lengthen the useful life of the tool.

It is yet another object of the present invention  
5 to provide tools with minimal amount of superabrasive required to perform the task for which the tool is designed, thereby reducing the cost of making the tool.

The above and other objects of the invention are  
10 achieved by the use of a novel method of forming the superabrasive surface. While the distribution of the diamond or cubic boron nitride particles has always been viewed as a complex, three dimensional problem, the present invention reduces the distribution of the  
15 superabrasive to a substantially two-dimensional process that is easy to manipulate and control, and which can be repeated with a high degree of accuracy. More specifically, the desired distribution of  
20 abrasive particles in a matrix body is achieved by assembling layers of matrix material that contain a controlled, preset pattern of abrasive particles. Each layer is formed by distributing the superabrasive grit into a layer of bonding matrix in a predetermined pattern. Each layer which is assembled to form a  
25 superabrasive impregnated segment can be of the same distribution pattern and concentration, or the distribution pattern and/or concentration may vary from layer to layer.

In accordance with one aspect of the present invention, each layer is assembled by disposing a layer of matrix material so that it may be used as a precursor. The superabrasive grit is then disposed in 5 the matrix material in a desire pattern. After the diamond particles are planted into the matrix material layer in a predetermined pattern, the process is repeated until a desired number of layers have been formed. These layers are then assembled to form the 10 desired three-dimensional body. Subsequently, the diamond tool is consolidated (e.g., by sintering or infiltration as described above) to form the final product.

By reducing the three-dimensional problem to a 15 two-dimensional solution through the use of the layers, the present invention can not only achieve the desirable diamond distribution pattern in the tool body, but can also provide the flexibility for possible manipulation of diamond concentration at 20 different parts of the same tool body. Thus, for example, diamond particles can be disposed in denser concentrations in some layers than others, and the layers with the greater diamond concentrations can be disposed within the three-dimensional structure 25 created in such a manner to prevent the uneven wear patterns that are typical in many prior art abrasive tools.

In accordance with another aspect of the present invention, each superabrasive layer is created by first forming a thin layer of bonding matrix. A template is then disposed on the bonding matrix. The 5 template has a plurality of apertures formed therein which are sized to receive superabrasive grit of a particular size, with one particle being disposed in each aperture. As the superabrasive grit fills the apertures, it may be subjected to pressure or otherwise moved into the bonding matrix. Because of the 10 template, the superabrasive grit which enters the bonding matrix is disposed in a predetermined pattern. A plurality of such superabrasive layers can then be bonded together and attached to the tool by brazing, 15 or some other process, to provide a three-dimensional superabrasive cutting or grinding member on the tool.

In accordance with another aspect of the present invention, the pattern in which the superabrasive grit is disposed may be uniform, or may be calculated to 20 provide superabrasive members with particular cutting abilities. For example, the superabrasive particles may be disposed in varied concentrations to compensate for uneven wear patterns. Thus, the diamond distribution for the cutting edge of a saw may 25 have a greater distribution of diamond particles on the lead edge and sides than on the middle portion which is generally subjected to less wear. Likewise, the sizes of the superabrasive particles can be

controlled to provide a cutting, grinding, etc., surface which is tailored to the particular purpose, such as to prevent chipping of the workpiece.

5

#### BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the invention will become apparent from a consideration of the following detailed description presented in connection with the accompanying drawings  
10 in which:

FIG. 1A shows a segment from a superabrasive tool formed by a plurality of linear, longitudinal layers disposed adjacent one another to form a three-dimensional superabrasive member;

15 FIG. 1B shows a cross-sectional view of one likely configuration of the tool segment shown in FIG. 1A, wherein a layer formed by a matrix material and a relatively large superabrasive is sandwiched between two layers of matrix materials which have smaller grit  
20 and higher concentration of the abrasive;

FIG. 2A shows a segment from a superabrasive tool formed by a plurality of arcuate, longitudinal layers which are attached to one another to form a three-dimensional superabrasive member;

25 FIG. 2B shows a cross-sectional view of a plurality of layers matrix material as may be used with the segment shown in FIG. 2A;

FIG. 3 shows another possible layout of a segment of a cutting tool with transverse layers configured with a denser concentration of abrasive material disposed, e.g., at a forward, cutting end of the  
5 three-dimensional superabrasive member;

FIG. 4 shows yet another layout of a segment wherein a three-dimensional superabrasive member is formed with progressively denser abrasive distribution toward, e.g., the upper surface of a tool with  
10 horizontal layers;

FIGs. 5A through 5D show one possible method for forming layers with controlled superabrasive distribution within the layer;

FIGs. 6A through 6C show an alternate method for  
15 forming one or more layers with controlled superabrasive distribution.

#### **DETAILED DESCRIPTION**

Reference will now be made to the drawings in  
20 which the various elements of the present invention will be given numeral designations and in which the invention will be discussed so as to enable one skilled in the art to make and use the invention. It is to be understood that the following description is  
25 only exemplary of the principles of the present invention, and should not be viewed as narrowing the pending claims.

Referring to FIG. 1A, there is shown a perspective view of a segment, generally indicated at 10, from a superabrasive tool (the remainder of which is not shown). The segment 10 is formed by a plurality of layers, 14, 16 and 18, which are impregnated with superabrasive particles, indicated by the circles 20. The plurality of layers 14, 16 and 18 are disposed adjacent to one another in a linear, longitudinal array so that the layers form the three-dimensional superabrasive segment 10.

As will be discussed in additional detail below, forming the segment 10 in a plurality of thin layers provides remarkably improved control over the distribution of the superabrasive particles. By controlling the distribution of the superabrasive particles within each layer and then combining layers, a three-dimensional segment can be formed in which distribution of the superabrasive particles is controlled in each dimension. This, in turn, enables the formation of segments which are particularly adapted to the likely use of the segment, be it for cutting, sawing, grinding, etc. By tailoring the distribution and concentration of the superabrasive particles within the segment 10, more precise control is given over performance of the tool under actual working conditions..

For example, when using a diamond saw blade to cut a rock (e.g., granite), the two sides of diamond

saw segments are cutting more materials than the center. As a result of the uneven wear, the cross section of the saw segment becomes convex in shape with the center bulging above both sides. This configuration typically slows the cutting rate of the saw blade. Moreover, the protruding profile may also cause the saw blade to deflect sideways in the cut slot. In order to maintain a straight cutting path, it is sometimes desirable to make a "sandwiched diamond segment" to reinforce both sides of the segment with layers impregnated with more superabrasive particles. Such a "sandwich segment" is difficult to manufacture by mixing diamond grit with metal powder by conventional means, but it can be easily accomplished by first planting diamond particles with desirable patterns in layered metal matrix and then assembling these layers together to form the sandwich segment.

In accordance with the present invention, a cutting segment can be formed to resist premature wear to the sides of the segment, thereby extending the cutting segment's useful life. Referring specifically to FIG. 1B, there is shown a cross-sectional view of the cutting segment 10 of FIG. 1A. Unlike the cutting segments of the prior art, the cutting segment 10 is formed of, for example, three layers, 14, 16 and 18 respectively. The middle layer 16 has a plurality of superabrasive particles 20a

which are of a first size (typically 40/50 U.S. mesh) and a first concentration (e.g. 20). The outer layers 14 and 18, in contrast, have a plurality of superabrasive particles 20b, which are of a second size (typically 50/60 mesh), smaller than the first size, and in a second concentration greater than that present in the middle layer 16 (e.g. 23). The smaller, more densely distributed superabrasive particles 20b provide the outer layers 14 and 18 with a greater resistance to wear as they cut through concrete, rock, asphalt, etc. Because the outer layers 14 and 18 are more resistant to wear, the cutting segment 10 resists formation of a convex outer surface, as has traditionally occurred with conventional tools. By maintaining a more planar cutting surface or even a concave profile, the cutting segment can maintain a straighter cutting path with a longer useful life. Moreover, by using a smaller grit on the flank of the saw, the finish of cut surface is more smooth. Furthermore, the chipping of the workpiece can be avoided.

Another advantage to the use of multiple layers of matrix with diamond or cubic boron nitride disposed therein is that the layers are easily formed into other desirable shapes for cutting, drilling, grinding, etc. For example, FIG. 2A shows a perspective view of a saw segment, generally indicated at 30, of a superabrasive tool formed by a plurality

offset pattern). A second plurality of layers, indicated at 58, are provided with a second concentration, less than the first concentration (represented by nine layers with an offset pattern of 5 superabrasive particles 20).

Many cutting tools are configured such that the cutting segment 50 is provided with a lead edge which performs a majority of the cutting and which receives most of the impact force when contacting the workpiece 10 to be cut. For example, a circular saw blade will usually have a plurality of teeth (saw segments), each tooth having a leading edge which takes the force of the cutting. Because the leading edge preforms a significant portion of the cutting, it is much more 15 susceptible to wear than are rotationally trailing portions of the tooth. When formed in accordance with the prior art, the teeth, however, often had similar concentrations of abrasive particles disposed therein. Over time the leading edge wears significantly, but 20 the trailing layers 58 remain with minimal wear. Eventually, the abrasive of the saw tooth is worn off the leading edge, while significant amounts remain on the tail end. Thus, a considerable amount of superabrasive is wasted when the blade is discarded.

25 The embodiment of FIG. 3 is specifically configured to overcome such concerns. The layers 56 and 58 are configured to provide substantially even wear across the cutting segment 50 by placing a larger

percentage of the superabrasive particles 20 near the leading edge, than on rotationally distal portions. Thus, by the time the leading edge has reached the end of its useful life, the remaining portions of the cutting segment 50 have also been worn out. Such controlled distribution of the superabrasive particles 20 decreases the use of the expensive material and lowers the cost for making the cutting segment 50 without hurting performance. Additionally, by providing more even wear, the cutting segment 50 will often be able to maintain most of its cutting speed until shortly before ending its useful life.

FIG. 4 shows yet another layout of a segment wherein a three-dimensional superabrasive member is formed with progressively denser abrasive distribution toward the upper surface of a tool with horizontal layers. It is often found that the speed of cutting tends to decrease with the wear of the tool. Thus, with a reduced concentration of superabrasive particles, the tool can maintain its current cutting speed at a constant power of the machine. Thus, as with the embodiment of FIG. 3, the controlled distribution of the superabrasive particles 20 forms an improved abrasive segment 70, while at the same time decreasing the cost of abrasive tools by saving those superabrasive particles which are not needed.

With routine experimentation and the teachings of the method of the present invention, those skilled in

the art will be able to customize cutting, drilling, grinding, polishing and other types of abrasive segments which are specifically formed to maximize their performance (i.e. cutting, drilling, grinding, etc.) over an extended useful life, while simultaneously decreasing the amount of expensive superabrasive which is used to form the tool.

Referring now to FIGs. 5A through 5D, there is shown one method for forming layers in accordance with the principles of the present invention. The first step of the method is to form a sheet 100 of matrix material 104 which will be bonded to the superabrasive particles 20. The sheet 100 of matrix material 104 can be formed from conventional metal powders as discussed above, or other bonding agents which have yet to be discovered.

There are many ways that a matrix powder can be made into the sheets 100. For example, the powder can first be mixed with a suitable binder (typically organic) and a solvent that can dissolve the binder. This mixture is then blended to form a slurry with a proper viscosity. In order to prevent the powder from agglomeration during the processing, a suitable wetting agent (e.g., menhaden oil, phosphate ester) may also be added. The slurry can then be poured onto a plastic tape and pulled underneath a blade or leveling device. By adjusting the gap between the blade and the tape, the slurry can be cast into a

sheet with the right thickness. The tape casting method is a well known method for making thin sheets out of powdered materials and it works well with the method of the present invention.

- 5        Alternatively, the powder can be mixed with a suitable binder and its solvent to form a deformable cake. The cake can then be extruded through a die with a slit opening. The gap in the opening determines the thickness of the extruded plate.
- 10      Alternatively, the material can also be drawn between two rollers with adjustable gap to form sheets with the right thickness.

It is desirable to make the sheets pliable for subsequent treatments (e.g., bending over a tool substrate which has a curvature). Therefore, a suitable organic plasticizer may also be added to provide the desired characteristics.

The use of organic agents for powder (metal, plastics, or ceramics) processing is documented in many text books and it is well known by those skilled in the art. Typical binders include polyvinyl alcohol (PVA), polyvinyl butyral (PVB), polyethylene glycol (PEG), paraffin, phenolic resin, wax emulsions, and acrylic resins. Typical binder solvents include methanol, ethanol, acetone, trichlorethylene, toluene, etc. Typical plasticizers are polyethylene glycol, diethyl oxalate, triethylene glycol dihydroabietate, glycerine, octyl phthalate. The organic agents so

introduced are to facilitate the fabrication of metal layers. They must be removed before the consolidation of metal powders. The binder removal process (e.g., by heating in a furnace with atmospheric control) is 5 also well known to those skilled in the art.

Once the sheet 100 of matrix material 104 is formed, a template 110 is laid on the top of the sheet. The template 110 contains apertures 114 that are larger than one abrasive particle 20, but smaller 10 than two abrasive particles, thereby allowing a single particle of the abrasive to be disposed at each specific location.

In this example, the thickness of the template is preferably between 1/3 to 2/3 of the height of the 15 average abrasive particle 20. However, other thicknesses may be used if appropriate accommodations are made for seating the abrasive particles in the desired locations.

After the template 110 is properly positioned, a 20 layer of abrasive particles 20 is then spread over the template so that each aperture 114 receives an abrasive particle. Those particles not falling into the apertures 114 in the template 110 are removed by tilting the substrate, sweeping the template with a 25 broom, or some other similar method.

As shown in FIG. 5B, a generally flat surface 120, such as a steel plate) is then laid over the particles 20 which rest in the apertures 114 in the

template 110. The flat surface 120 presses the abrasive particles 20 at least partially into the pliable sheet 100 of matrix material 104 to seat the particles.

5        After removing the template 110, the flat surface 120 is used again to press the abrasive particles 120 firmly into the sheet 100 of matrix material 104 as shown in FIG. 5C. While the flat surface 120 is preferable, those skilled in the art will appreciate  
10      that there may be occasions when it is desirable to have abrasive particles protruding above the metal sheet 100 with equal height. Alternatively, some of the abrasive particles 20 may be wanted to extend outwardly from the sheet 100 of matrix material more  
15      than that of other abrasive particles. In such situations, a contoured or otherwise shaped surface could be used to seat some of the abrasive particles 20 deeper into the sheet 100 of matrix material 104, than other particles.

20       If desired, the process shown in FIGs. 5A through 5C can be repeated on the other side of the sheet 100 of matrix material 104 (as shown in FIG. 5D), to form an impregnated layer having abrasive particles 20 distributed throughout the layer in some  
25      predetermined, desired pattern. The process is typically repeated several times to obtain multiple thin layers or sheets 100 which are impregnated with the abrasive particles 20. Of course, each sheet 100

needs not have the same distribution pattern for the abrasive particles 20, nor does it need the concentration of the abrasive particles be the same.

The abrasive impregnated sheets 100 are next cut 5 to any desired size and shape. The sheets 100 are then assembled to form the tool segment or the entire tool body where appropriate. Typically, the assembly of the sheets 100 is accomplished by a known method such as cold compaction with a press. The "green" 10 body so formed can then be consolidated to form a final tool product by conventional method of sintering or infiltration as described by following the examples.

While the method described in FIGs. 5A through 5D 15 is preferred for many applications, there are instances where it is desirable to have the abrasive particles 20 extend outwardly from the sheet 100 of matrix material. For example, some tools may only have one layer of abrasive. This can be accomplished 20 simply by leaving the template 110 in place when performing the steps shown in FIG. 5A and 5B, and not further pressing the particles 20 into the matrix material once the template has been removed.

In the alternative, FIGs. 6A through 6C show a 25 side view of an alternate to the method discussed in FIGs. 5A through 5D. The sheet 130 of matrix material in FIGs. 6A through 6C is thinner than the height of the superabrasive particles 20. Thus, in this

procedure, when the particles are pressed into the sheet 130, the particles 20 would protrude above the matrix material 134.

Although the present invention is intended for 5 making three-dimensional abrasive tools, the teachings contained in the present application can readily be applied to two-dimensional tools as well. For example, U.S. Patent Nos. 3,894,673 and 4,108,576 describe certain brazed diamond tools that contain a 10 single layer of diamond particles. These particles are brazed onto a tool shank by a chromium containing alloy. Such diamond tools are widely marketed (e.g., by Abrasives Technology of U.S.A.) for cutting and grinding non-ferrous materials (e.g., stones or 15 glass).

However, the distribution of diamond particles on these tools are typically random and non-uniform. The methods illustrated in FIGS. 5A through 6C can readily be applied to such tools to improve the diamond 20 distribution. In this case, the method offers several advantages over the conventional technology as described by these patents. For example, by making diamond particles distributed in a desirable pattern, the load of cutting can be evenly distributed to all 25 diamond particles. As a result, the tool can cut faster with a longer life.

The performance may be further improved by having a braze layer of uniform thickness. This uniformity

can allow a better diamond retention and easier debris removal. Moreover, by fully utilizing each diamond particle for cutting, the concentration of diamond can be reduced. As discussed, diamond cost often accounts 5 for about half of the total manufacturing cost of a diamond tool. Hence, by practicing this invention, manufacturing cost can be reduced substantially.

Also shown in FIG. 6A through 6C is the principle that the spacings of the apertures in the template 130 need not be uniform. Rather, variations in spacing 10 can be provided to facilitate different concentrations on various portions of the sheet 130 of matrix material 134. Likewise, by controlling the size of the apertures 138 and the order in which the diamond 15 particles are placed in the apertures, a single layer could be provided with particles of different sizes.

In addition to being able to improve the performance of the tool and to reduce the cost of the manufacturing, this invention also provides a easier 20 method for making thin bladed tools. For example, the electronic industry requires using larger and larger silicon wafers (now 12 inches in diameter). Hence, thinner saw blades for slicing silicon crystals with lower kerf loss, and thinner dicing wheels for 25 grooving silicon chips with tighter partitions have been in demand.

Prior to the present invention, it has been extremely difficult to make very thin tools that

contain evenly distributed diamond particles. The present invention provides an alternative method for making such tools. For example, it has been discovered that by mixing micron powders of diamond, a 5 blend of metal powders (e.g., bronze and cobalt) and a suitable binder, the material can be rolled to a thickness thinner than 0.1 mm. By firing this thin sheet and mounting it on a tool holder, a thin dicing wheel can be made.

10        In the alternative to the above, it has been found in accordance with the present invention that some of the advantages of the controlled distribution, multilayered superabrasive configurations described above can be achieved without the use of a template. 15        More specifically, the abrasive particles can also be mixed in with the matrix powder and made as an ingredient of the layered sheet. In this case, the distributions of abrasive particles are still somewhat random. Even so, their distribution is typically more 20        uniform than that in a conventional abrasive body. The segregation of abrasive particles and matrix powders discussed in the background section is less extensive in a substantially two-dimensional sheet than in a three-dimensional body. This is 25        particularly true for sheets made by a deforming process (e.g., by rolling). In this case, abrasive particles are further spread out in the matrix by the shearing action of the rollers.

This invention may also be applicable to other applications not related to making abrasive tools. For example, graphite or metal sheets planted with diamond particles may be used as seeds for diamond growth under high pressure and temperature.

Industrial diamonds are typically produced by compressing alternative layers of graphite and metal catalyst (e.g., Fe, Co, or Ni alloy) to high pressure and heated above the melting point of the catalyst.

Diamond will then nucleate randomly on the interface of these layers. The quality of the diamond crystal formed often suffers by the impingement of growing crystals that are distributed unevenly. Hence, the yield and cost of diamond synthesis can be substantially improved by making the nuclei distributed uniformly. This invention can provide layers of either graphite or metal catalyst with a pre-determined pattern of diamond seeds. If organic binders are introduced during the fabrication of these layers, they can be removed by heating in a furnace before loading into the press.

#### Example 1

40/50 mesh diamond grit (SDA-85<sup>†</sup> made by De Beers Company) were mixed with metal powder to form a mixture with diamond concentration of 20 (5% of total volume). Five different proportion of cobalt (about 1.5 micrometer in size) and bronze (about 20

micrometers in size) were used for the matrix powder. An acrylic binder was added (8% by weight) to the mixture and the charge was blended to form a cake.

The cake was then rolled between two stainless steel 5 rollers to form sheets with a thickness of 1 mm. These sheets were cut in the shape of saw segments with a length of 40 mm and width of 15 mm. Three each of such segments were assembled and placed into a typical graphite mold for making conventional diamond 10 saw segments. The assembled segments were pressed and heated by passing electric current through the graphite mold. After sintering for three minutes, the segments were consolidated to a height of 9 mm with less than 1% porosity. Twenty-four segments for each 15 composition were fabricated. They were brazed onto a circular saw of 14 inches in diameter. These five blades were used for cutting granites and found to perform equal or better than those with higher diamond concentrations (e.g. 23) made by conventional methods.

Microscopic examination of the worn segment indicated 20 that although diamond particles were not planted into the layered matrix, they were distributed more evenly than segments prepared by the traditional method. The segregation of particles in layered matrix was considerably less than that in a thick body of 25 conventional segments.

**Example 2**

The same procedures were followed as Example 1, but with 8 thinner layers (0.4 mm) for each segment. The diamond concentration was reduced to 15 and 5 particles were planted according to the illustration as shown in FIGs. 5A through 5D. The diamond distribution was much improved. As a result, the performance of these blades were equal or better than those made by conventional methods with diamond 10 concentration of 20.

**Example 3**

Iron powders of about 100 mesh were mixed with an S-binder made by Wall Colmonoy Company to form a cake. 15 The cake was then rolled to form sheets of 0.4 mm in thickness. 40/50 mesh SDA-100<sup>\*</sup> diamond grit was planted into these sheets to attain a concentration of 15. These diamond containing sheets were cut in the shape of saw segments with a length of 40 mm and width 20 of 9 mm. Eight of such segments were assembled as a group and placed in a graphite mold. Twenty-four groups were placed horizontally, and another twenty-four groups were placed vertically in the graphite mold. Nicrobraz LM powder (-140 mesh) (made by Wall 25 Colmonoy Company) was added on the top of these segments. These samples were heated in a vacuum furnace ( $10^{-5}$  torr) to 1050 °C for 20 minutes for horizontally placed segments, and 30 minutes for

vertically placed segments. The melted LM alloy (Ni-Cr-B-Si with a liquidus point at 1000 °C) infiltrated into these segments and filled the porosity. The excess LM braze on these segments were ground by electrode discharge (EDG). Each of the 24 segments so fabricated were brazed onto a 14 inch (diameter) circular saw blade. These blades were used to cut granite and showed marked improvement over conventional saw blades.

10

#### Example 4

Nicrobraz LM powder was mixed with an acrylic binder and rolled to form layers of about 0.25 mm. 40/50 mesh MBS-960 diamond grit manufactured by General Electric Company was planted into these metal layers according to the method as illustrated in Figure 5. These diamond plated metal layers were cut in proper size and wrapped around 2,000 beads (pearls) of wire saw. The beads preferably have a taper angle between 3 and 5 degrees. These beads (10 mm in diameter by 10 mm long) were divided into two groups, one contains 280 crystals (about 0.2 carat) per bead; and the other, 400 crystals (about 0.3 carat). These beads were heated in a vacuum furnace to a temperature of 1,000 °C for 8 minutes. These beads were mounted on several wire saws and used to cut marble, serpentine and granite. The performance of these beads was found to be superior to conventional beads.

The latter beads were typically made by either hot pressing or electroplating. These conventional beads may contain a much higher amount of diamond (up to 1 carat) per bead.

5           Example 5

The same method as described by Example 4, but applied to other products, e.g., circular saws, thin-wall core bits, and curvature grounder. Each of these products shows superior performance over conventional 10 electro-plated diamond tools having a similar or higher superabrasive concentrations.

The above description and examples are intended only to illustrate certain potential uses of this invention. It will be readily understood by those 15 persons skilled in the art that the present invention is susceptible of a broad utility and applications.

Many embodiments and adaptations of the present invention other than those herein described, as well 20 as many variations, modifications and equivalent arrangements will be apparent from or reasonably suggested by the present invention and the forgoing description thereof without departing from the substance for scope of the present invention.

Accordingly, while the present invention has been 25 described herein in detail in relation to its preferred embodiment, it is to be understood that this disclosure is only illustrative and exemplary of the present invention and is made merely for the purpose

of providing a full and enabling disclosure of the invention. The forgoing disclosure is not intended to be construed to limit the present invention or otherwise to exclude any such other embodiment, 5 adaptations, variations, modifications and equivalent arrangements, the present invention being limited only by the claims appended hereto and the equivalents thereof.

**CLAIMS**

What is claimed is:

1. An abrasive tool having an abrasive impregnated segment comprising:
  - 5 a matrix material configured for bonding abrasive particles; and
  - a plurality of abrasive particles distributed in the matrix material in a predetermined pattern.
- 10 2. The abrasive tool according to claim 1, wherein the plurality of abrasive particles are selected from the group consisting essentially of diamond, cubic boron nitride, alumina and silicon carbide.
- 15 3. The abrasive tool according to claim 1, wherein the abrasive impregnated segment is formed by a plurality of matrix material layers, each layer being impregnated with abrasive particles, and wherein the plurality of layers are disposed adjacent one another.
- 20 4. The abrasive tool according to claim 3, wherein the abrasive particles in one of the layers are larger than the abrasive particles in at least one of the other layers.
- 25 5. The abrasive tool according to claim 4, wherein the plurality of layers includes at least one outer layer and at least one inner layer, and wherein the abrasive particles of the at least one inner layer

are larger than the abrasive particles of the at least one outer layer.

6. The abrasive tool according to claim 5,  
5 wherein the abrasive segment is configured with two outer layers and at least one inner layer disposed between the outer layers, wherein each of the outer layers and the at least one inner layer has abrasive particles disposed therein, and wherein the abrasive particles disposed in the at least one inner layer are  
10 larger than those disposed in the outer layers.

7. The abrasive tool according to claim 3,  
wherein at least one of the layers has a greater concentration of abrasive particles than at least one  
15 of the other layers.

8. The abrasive tool according to claim 7,  
wherein the plurality of layers includes at least one outer layer and at least one inner layer, and wherein the at least one outer layer has a greater  
20 concentration of abrasive particles than the at least one inner layer.

9. The abrasive tool according to claim 8,  
wherein the abrasive segment is configured with two outer layers and at least one inner layer disposed  
25 between the outer layers, wherein each of the outer layers and the at least one inner layer has abrasive particles disposed therein, and wherein the abrasive particles disposed in the outer layers are disposed in

greater concentration than the abrasive particles in the at least one inner layer.

10. The abrasive tool according to claim 7, wherein the plurality of layers includes at least one 5 first layer having a first concentration of abrasive particles, at least one second layer having a second concentration less than the first concentration, and at least one third layer having a third concentration less than the second concentration.

10 11. The abrasive tool according to claim 7, wherein the abrasive impregnated segment has a leading edge configured to initially impact a surface to be cut, wherein the segment is formed by a plurality of layers 15 and wherein the layers adjacent the leading edge having a higher concentration of abrasive particles than layers remote from the leading edge.

12. The abrasive tool according to claim 1, wherein the 20 abrasive particles are distributed in a uniform pattern throughout the impregnated segment.

13. The abrasive tool according to claim 12, wherein the abrasive particles are uniformly distributed throughout the tool.

25 14. The abrasive tool according to claim 1, wherein the tool has abrasive particles distributed therethrough, and wherein the tool has an outer

portion having a higher concentration of abrasive particles disposed therein.

15. The abrasive tool according to claim 1, wherein the segment has an impacting surface formed thereon and wherein the abrasive particles are distributed in higher concentration adjacent the impacting surface.

16. The abrasive tool according to claim 1, wherein the segment is formed by a plurality of two-dimensional layers assembled together to form a three-dimensional segment.

17. An abrasive tool comprising a plurality of layers formed from a matrix material for holding abrasive particles, and a plurality of abrasive particles distributed in the layers of matrix material, the layers being attached to one another to form a three-dimensional tool abrasive segment.

18. The abrasive tool of claim 17, wherein at least one of the layers is 1 millimeter thick or less.

20 19. The abrasive tool of claim 17, wherein the layers have been consolidated together by a method selected from the group consisting of brazing, sintering or infiltration.

25 20. The abrasive tool of claim 17, wherein the abrasive particles are distributed within the layers in predetermined patterns.

21. The abrasive tool of claim 20, wherein the distribution of the abrasive particles is uniform in at least one of the layers.

22. An abrasive tool comprising at least one layer of matrix material with abrasive particles formed therein, the layer being 1 millimeter or less in thickness and formed by rolling the matrix material and abrasive particles between rollers to improve uniformity in the distribution of the abrasive particles.

23. A method for forming an abrasive tool body, the method comprising:

(a) forming a sheet of matrix material configured for bonding to abrasive particles; and

(b) disposing a plurality of abrasive particles in the sheet of matrix material in a predetermined pattern.

24. The method according to claim 23, wherein the method comprises, more specifically, placing a template with a plurality of apertures formed therein on the sheet of matrix material prior to disposition of the plurality of abrasive particles so that placement of the abrasive particles is controlled by the position of the apertures, thereby selectively limiting placement of the abrasive particles in the sheet of matrix material to the positions of the apertures.

25. The method according to claim 24, wherein the method comprises, more specifically, using a template formed from a sieve.

26. The method according to claim 24, wherein 5 the template is formed by a plate having a plurality of apertures formed therein, the apertures being configured in a predetermined pattern.

27. The method according to claim 26, wherein each aperture has a diameter which is greater than a 10 diameter of the abrasive particles to be positioned thereby, but less than twice the diameter of the abrasive particles.

28. The method according to claim 23, wherein 15 the method comprises, more specifically, forming the sheet of matrix material by tape casting.

29. The method according to claim 23, wherein the method comprises, more specifically, forming the sheet of matrix material by rolling.

30. The method according to claim 23, wherein 20 the method comprises, more specifically, forming the sheet of matrix material by extrusion.

31. The method according to claim 23, wherein the method comprises, more specifically, forming a plurality of layers of matrix material having abrasive 25 particles disposed therein, and attaching the layers together to form a three-dimensional abrasive segment.

32. A method for forming a layer of abrasive impregnated matrix material having improved abrasive distribution, the method comprising:

(a) forming a layer having a mixture of matrix material and abrasive particles; and

(b) rolling the layer of mixture to form a layer no greater than 1 millimeter thick.

33. A method of making layers catalyst for diamond synthesis, the method comprising:

(a) forming at least one layer of a catalyst; and  
(b) planting a plurality of diamond particles in the catalyst in a predetermined pattern.

34. The method according to claim 33, therein the method further comprises disposing organic binders in the catalyst prior to planting the plurality of diamond particles, and removing the heating in a furnace before pressing the catalyst and diamond particles.

35. A method of making a source material for diamond synthesis, the method comprising:

(a) providing a layer of graphite; and  
(b) planting a plurality of diamond particles in the layer of graphite in a predetermined pattern.

36. The abrasive tool according to claim 1, wherein the abrasive impregnated segment is formed by at least one layer of matrix material.

37. The abrasive tool according to claim 36,  
wherein the at least one layer of matrix material  
contains at least one layer of abrasive particles.

38. The abrasive tool according to claim 37,  
5 wherein the tool is a wire saw that it at least  
partially surrounded by the matrix material that  
contains the abrasive particles.

39. The abrasive tool according to claim 38,  
wherein the tool is a wire saw that contains diamond  
10 beads overcoated with diamond.

40. The abrasive tool according to claim 39,  
wherein the diamond bead has a taper angle of 3 to 5  
degrees.

41. The abrasive tool according to claim 36,  
15 wherein the matrix material is consolidated by a  
method selected from the group consisting of brazing,  
sintering and infiltration.

1/4

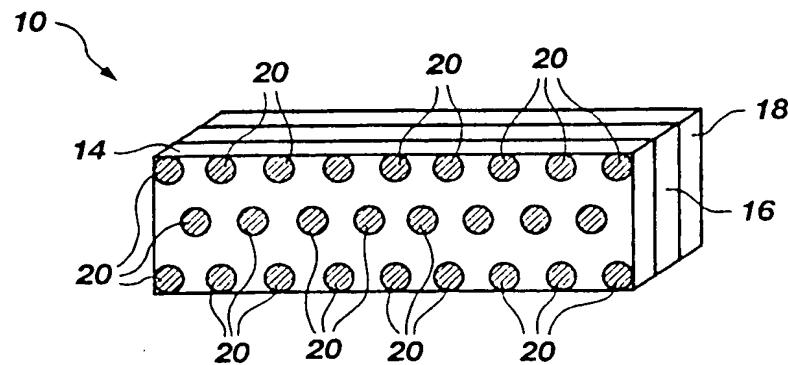


Fig. 1A

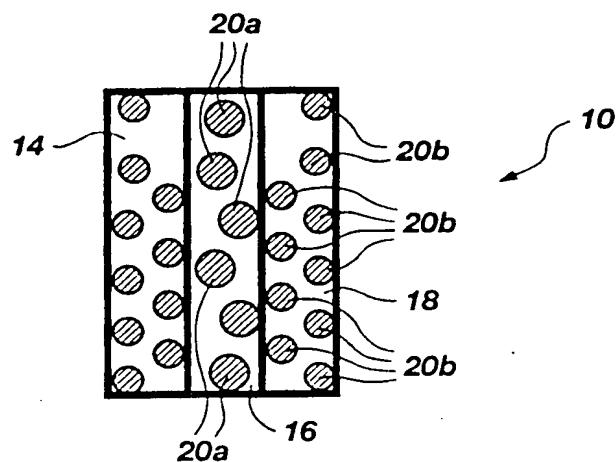


Fig. 1B

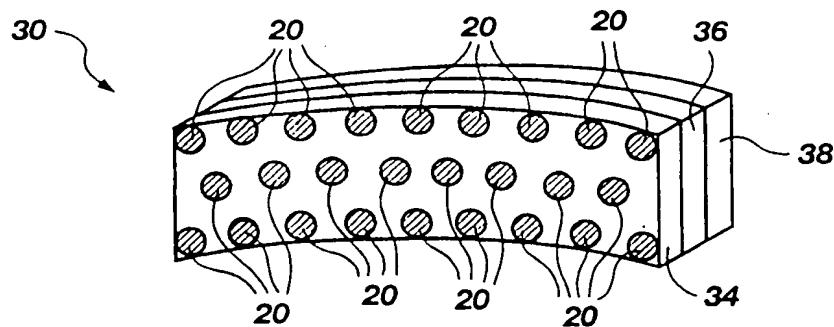
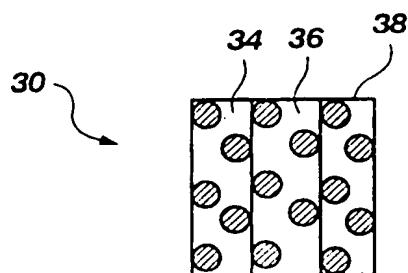
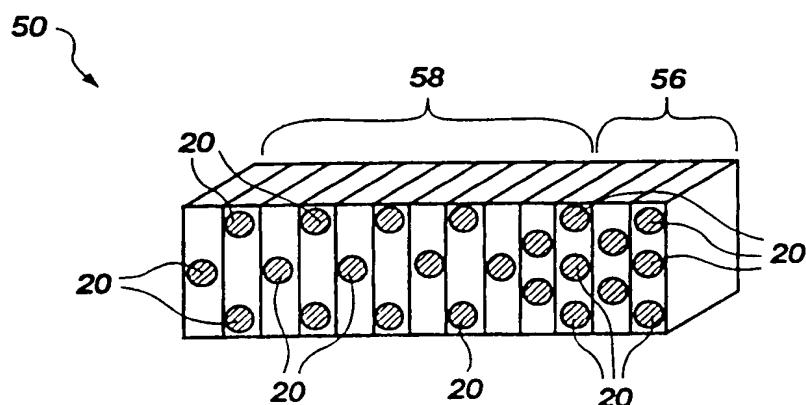
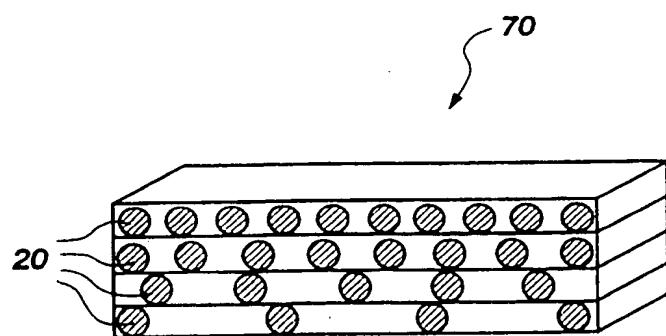
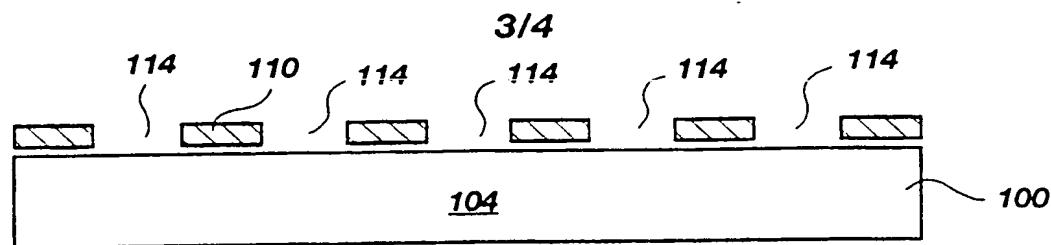
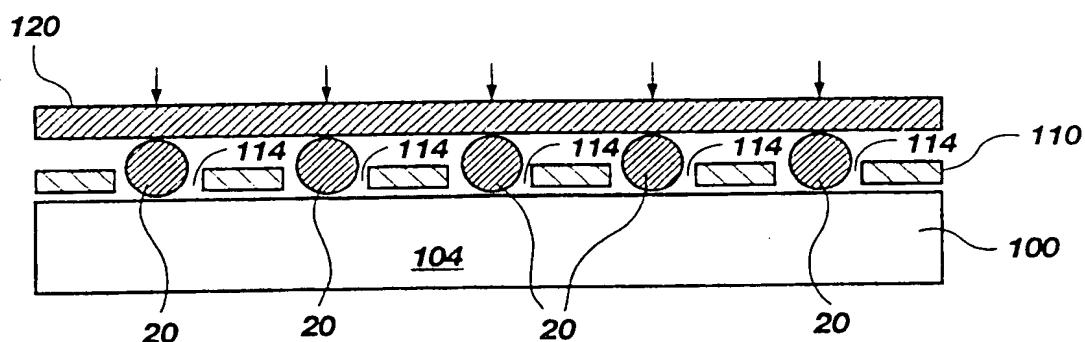
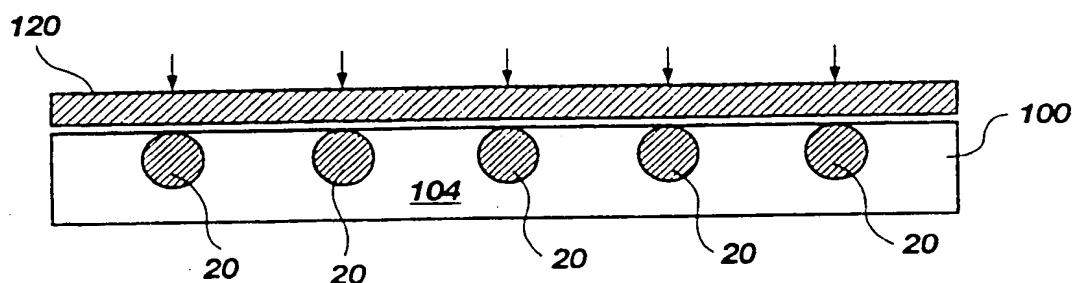
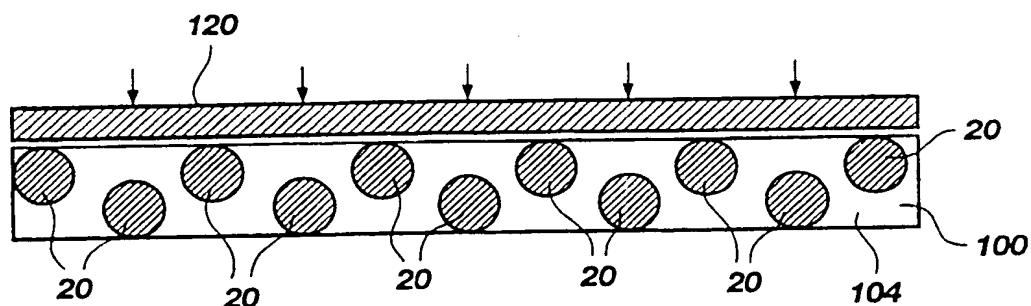


Fig. 2A

2/4

**Fig. 2B****Fig. 3****Fig. 4**

*Fig. 5A**Fig. 5B**Fig. 5C**Fig. 5D*

4/4

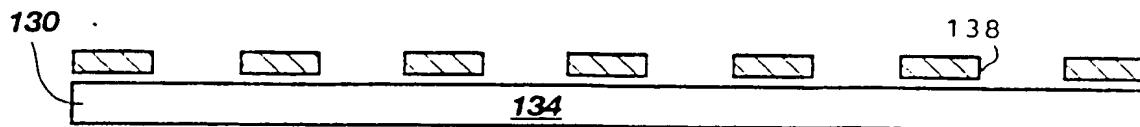


Fig. 6A

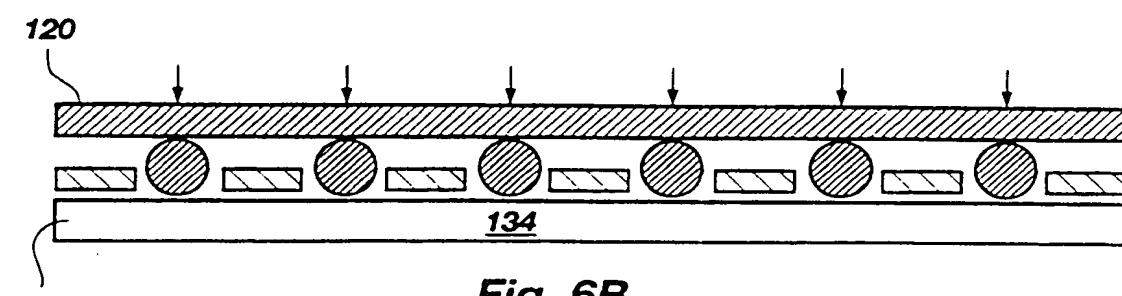


Fig. 6B

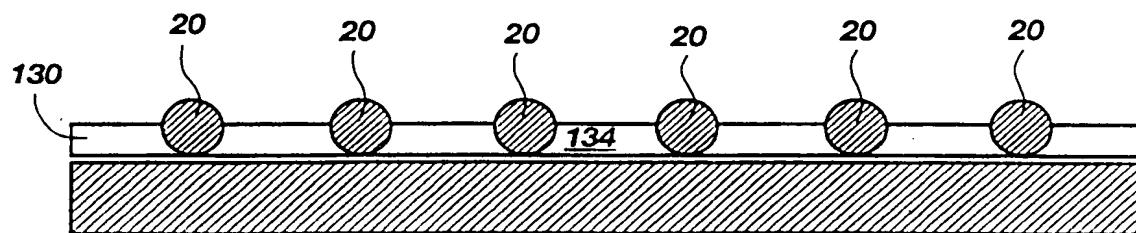


Fig. 6C

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US98/05951

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B24D 11/00

US CL :451/540

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 451/527,529,533,540; 51/297; 125/16.02,21,22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, 2,725,693 A (SMITH) 06 December 1955	1-41
Y	US, 2,952,951 A (SIMPSON) 20 September 1960, see entire document, specifically figure 2	1-41
Y	US, 3,146,560 A (HURST) 01 September 1964, see entire document.	1-41
Y	US 4,712,552 A (PANGBURN) 15 December 1987, see entire document, specifically figures 9 and 10.	1-41
A	US, 4,866,888 A (MURAI et al) 19 September 1989.	1-41
A	US 5,176,155 A (RUDOLPH, JR.) 05 January 1993.	1-41.

 Further documents are listed in the continuation of Box C. See patent family annex.

• Special categories of cited documents:	*T*	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
• A* document defining the general state of the art which is not considered to be of particular relevance	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
• E* earlier document published on or after the international filing date	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
• L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*&*	document member of the same patent family
• O* document referring to an oral disclosure, use, exhibition or other means		
• P* document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

19 JUNE 1998

Date of mailing of the international search report

16 JUL 1998

Name and mailing address of the ISA/US  
Commissioner of Patents and Trademarks  
Box PCT  
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

Timothy V. Eley

Telephone No. (703) 308-1824 Group 3700-3708

Shaila Vency  
Paralegal Specialist

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US98/05951

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B24D 11/00  
 US CL :451/540

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 451/527,529,533,540; 51/297; 125/16.02,21,22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, 2,725,693 A (SMITH) 06 December 1955	1-41
Y	US, 2,952,951 A (SIMPSON) 20 September 1960, see entire document, specifically figure 2	1-41
Y	US, 3,146,560 A (HURST) 01 September 1964, see entire document.	1-41
Y	US 4,712,552 A (PANGBURN) 15 December 1987, see entire document, specifically figures 9 and 10.	1-41
A	US, 4,866,888 A (MURAI et al) 19 September 1989.	1-41
A	US 5,176,155 A (RUDOLPH, JR.) 05 January 1993.	1-41.

Further documents are listed in the continuation of Box C.  See patent family annex.

* Special categories of cited documents:	*T*	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A* document defining the general state of the art which is not considered to be of particular relevance		
*B* earlier document published on or after the international filing date	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
*O* document referring to an oral disclosure, use, exhibition or other means	*Z*	document member of the same patent family
*P* document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
19 JUNE 1998	16 JUL 1998
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer Timothy V. Eley Paralegal Specialist
Faxsimile No. (703) 305-3230	Telephone No. (703) 308-1824 Group 3200-3700